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Effects of musical training on pitch discrimination of resolved and unresolved complex tones

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Introduction

Musicians typically show enhanced pitch-discrimination ability compared to non-musicians, consistent with the hypothesis that musicians are more sensitive to some acoustic features critical for both speech and music processing (see 1, 2, 3, 4). It has been debated whether this perceptual enhancement, so far mainly observed for complex tones containing resolved harmonics (1), can be ascribed to higher peripheral frequency selectivity (5), increased sensitivity to spectro-temporal features due to finer representations at a cortical level (6, 7), or an enhanced ability to attend to and extract such features.

The present study investigated whether musical training enhances pitch-discrimination performance for complex tones containing resolved vs. unresolved harmonics to the same extent (experiment 1), and whether this enhancement can be ascribed to increased frequency selectivity (experiment 1) or to a higher effort in performing the task indicated by task-evoked pupil dilations (experiment 2).

Method

Experiment I: Pitch discrimination

- Pitch discrimination of complex tones was measured via difference limens for fundamental frequency (F_0 DLs).
- Participants: 14 listeners (6 musicians, 8 non-musicians).
- Stimuli: complex tones filtered in either a **low** (LF: 0.3-1.5 kHz) or a **high** (HF: 1.5-3.5 kHz) frequency region to vary the resolvability of the harmonics.
- Paradigm: 3 AFC, two intervals contained a reference complex tone with a fixed F_0 , and one interval contained a deviant complex tone with a larger F_0 .
- Measure the smallest detectable ΔF_0 .

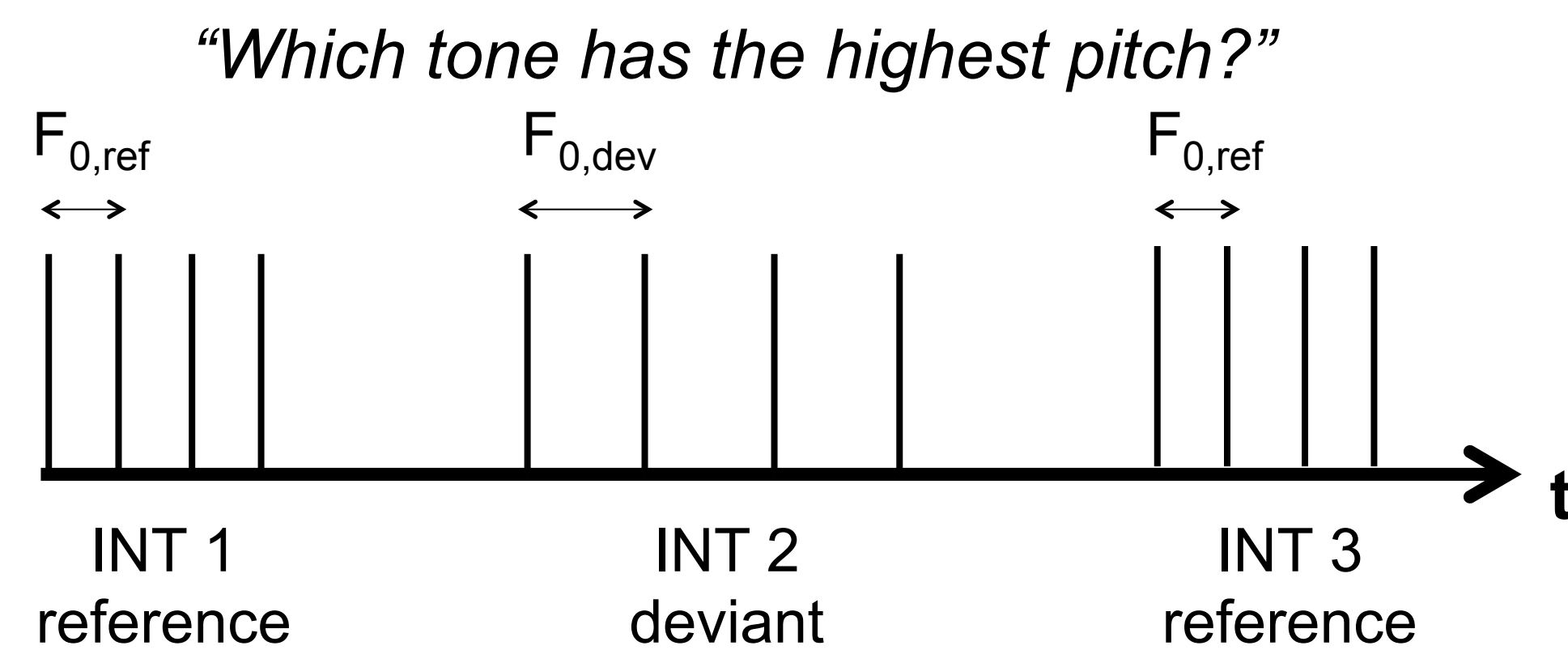


Figure 1 Stimulus presentation for the pitch discrimination task in a 3 AFC task. Subjects were asked to press a response button after stimulus presentation.

Experiment II: Pupillometry

- Task-evoked pupil dilation was measured during a pitch-discrimination task.
- Participants: 6 musicians (4 from Experiment I), 5 non-musicians (4 from Experiment I)
- Variation of task difficulty: ΔF_0 was adjusted to be below, at and above the individual pitch-discrimination threshold from experiment I.
- Variation of harmonic resolvability: three different F_0 s (100, 200, and 500 Hz) were tested, filtered in **LF** and **HF** regions.

		F_0		
		100 Hz	200 Hz	500 Hz
ΔF_0	> threshold	Resolved Easy	Resolved Easy	Resolved Easy
	= threshold		Mid-Resolved Medium-difficulty	Resolved Easy
	< threshold	Unresolved Difficult		

Figure 2 Six stimulus conditions of varying task-difficulty and harmonic resolvability were tested during the pupillometry experiment.

Results

Experiment I: Pitch discrimination

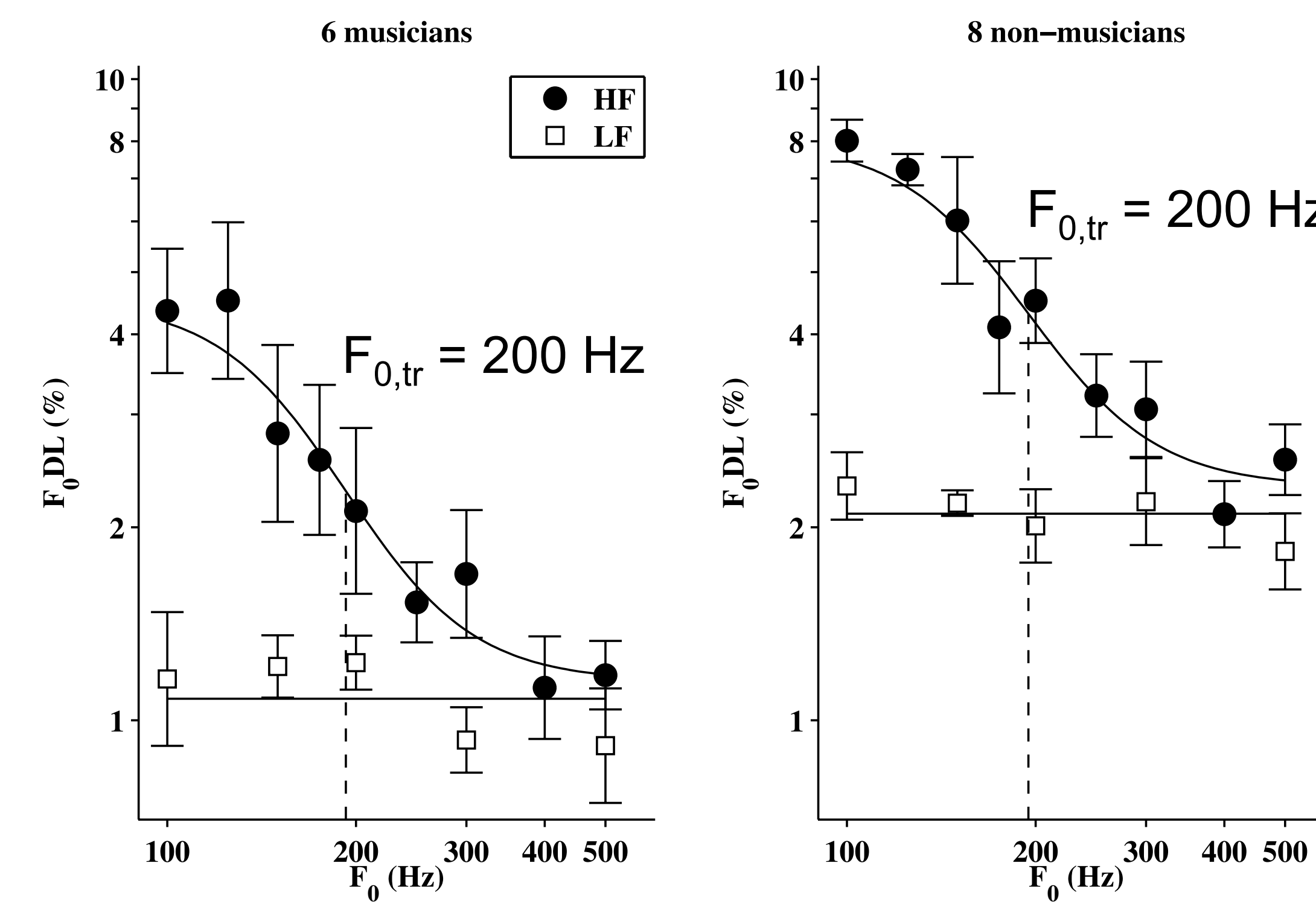


Figure 3 Pitch discrimination thresholds as a function of F_0 for complex tones filtered either in a low (white squares) or high (black circles) frequency region. Left panel: musicians, right panel: non-musicians.

- Musicians: benefit by a factor of 2 in the pitch discrimination threshold for both resolved and unresolved complexes (see 1, 2, 3).
- Similar transition point ($F_{0,tr}$) for musicians and non-musicians at around 200 Hz.
- Since $F_{0,tr}$ was shown to correlate with measures of frequency selectivity (see 8), these findings suggest that the enhanced performance for musicians may not be ascribed to an increased peripheral resolvability.

Experiment II: Pupillometry

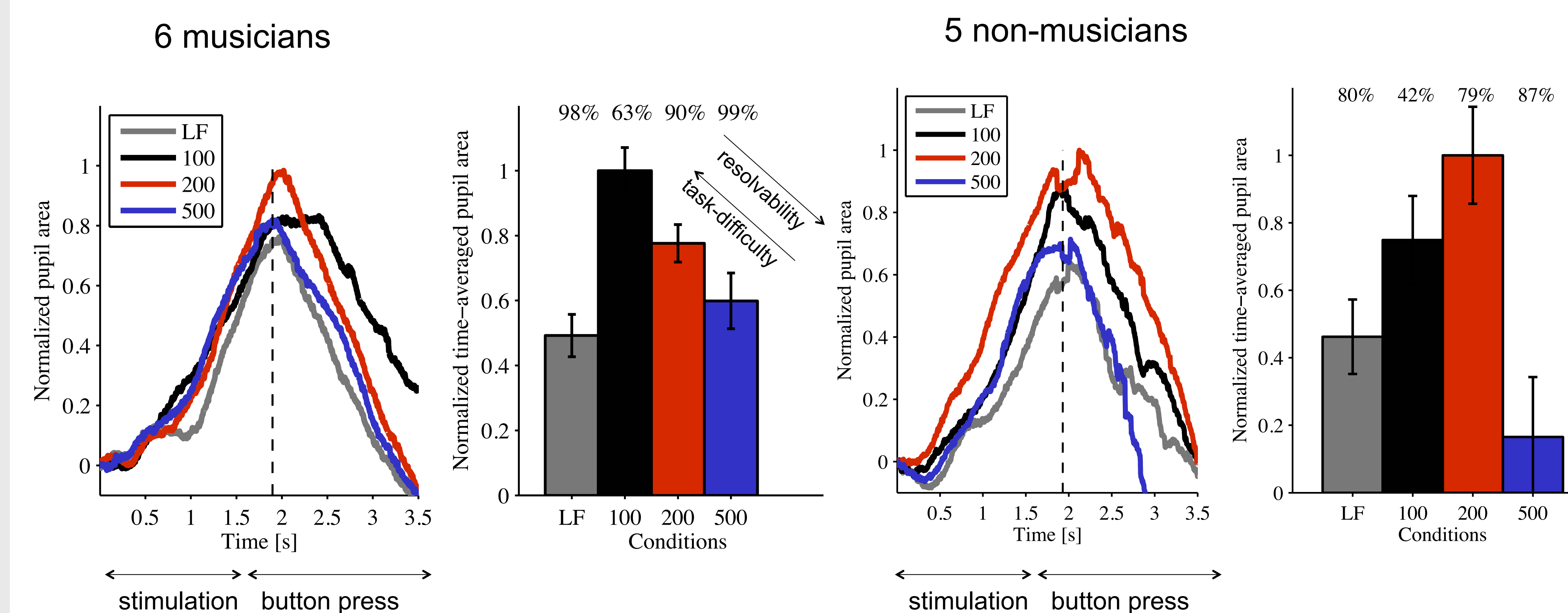


Figure 5: Left panels: normalized pupil dilation as a function of time (averaged across 6 musicians and 5 non-musicians). Right panels: time-averaged value of pupil dilation, calculated from the maximum dilation point (around 2 s) until 3.5 s after stimulus onset. The percentages refer to the obtained average performance for each condition. All pupil size data are normalized relative to the initial baseline and divided by the maximum range of dilation (according to 9).

Musicians:

- increase in task-induced pupil dilation with:
 - increasing difficulty of the task
 - decreasing resolvability of the stimuli

Non-Musicians:

- increase in task-induced pupil dilation:
 - from easy-to-medium task difficulty
- decrease in task-induced pupil dilation:
 - for unresolved complex tones and high task difficulty
- might have given up when the task was too demanding (cognitive processing overload, see 10).

Discussion

- Musically-trained listeners obtained smaller (better) behavioral pitch-discrimination thresholds than non-musicians by a factor of about 2 in both resolved and unresolved conditions, indicating that the presence of resolved harmonics is not necessary for enhanced pitch discrimination following musical training.
- Possible factors enhancing performance:
 - higher peripheral frequency selectivity ✗
 - higher task-induced effort for unresolved tones and high task difficulty ✓
 - finer spectro-temporal cues at higher levels ?

Perspectives

- Confound of the current paradigm:
 - all resolved conditions are tested with an easy task, unresolved with a difficult task
- New paradigm:
 - test HF at 3x3 levels of difficulty and resolvability
 - disentangle resolvability and task difficulty
 - measure pupil dilations (pupillometry experiment) and, additionally, cortical activation (functional magnetic resonance imaging, fMRI)

		F_0		
		100 Hz	200 Hz	500 Hz
ΔF_0	> threshold	Resolved Easy	Mid-Resolved Easy	Resolved Easy
	= threshold	Unresolved Medium-difficulty	Mid-Resolved Medium-difficulty	Resolved Medium-difficulty
	< threshold	Unresolved Difficult	Mid-Resolved Difficult	Resolved Difficult

Figure 6 Design of a new paradigm with eleven stimulus conditions of varying task-difficulty and harmonic resolvability.

Conclusions

- Our behavioral findings indicate a similar perceptual benefit for pitch-discrimination of resolved and unresolved complex tones in musicians.
- This benefit seems not to be ascribed to sharper peripheral filtering.
- Higher task-induced effort may partly explain the enhanced performance of musicians for unresolved complex tones.
- Future work may clarify whether increased pupil dilation can be explained as an effect of stimulus resolvability and/or task difficulty.
- Future work on fMRI may clarify whether musicians show a higher sensitivity to fine spectro-temporal cues at a cortical level.

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